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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

The High Speed Diesel

Maintenance and Lubrication

PUBLISHED BY
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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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The High Speed Diesel

Maintenance and Lubrication

HIGH SPEED Diesel lubrication is a two-way proposition. Just as proper lubrication maintains high engine efficiency so will improper operating conditions result in decreased lubrication efficiency. Not only is the Diesel engine a good instrument for evaluating the quality of the lubricating oil but also the crankcase oil analysis is a good indicator for detecting engine condition.

When ring sticking or similar difficulty occurs, one is apt to conclude that "it's the oil". Actually, when first line approved lubricants of responsible oil companies are used, mistreatment of the engine is usually responsible for any faulty lubrication encountered. The proper method of attacking this sort of maintenance problem is to check all operating conditions, making such corrections as necessary and observing results. This article is a discussion of those engine factors which influence lubrication results. Before discussing the subject in detail, let's look at the general considerations involved in getting best performance out of the small high speed Diesel operating around 2000 R.P.M.

The internal combustion engine is primarily an instrument for burning liquid fuels and converting the energy released into rotative power.* The Diesel differs from the gasoline engine in that the fuel used is of higher boiling range and requires a higher engine temperature for conversion to the gaseous state which is necessary before combustion can take place. This does not mean that all parts of the Diesel run hotter than similar parts in a gasoline engine for such is not the case. After combustion, the gases in a Diesel are allowed to expand further and exhaust temperatures are lower; also, due to the higher efficiency, less heat escapes to the cooling water. It is necessary, therefore, to overcome the normal tendency of the Diesel to run cool when actually more heat is necessary to properly burn the heavier fuel. To achieve this, less cooling is applied to the parts adjacent to the combustion chamber. Even with the additional heat applied, Diesel fuel is seldom burned completely and soot forms in the engine.

For best performance, therefore, the operator of a high speed Diesel should, 1) select a fuel having as good burning qualities as economic considerations permit; 2) operate the engine hot enough to burn the fuel properly; 3) maintain the fuel injection system so that good combustion is assured, and 4) use a lubricating oil which will withstand the high temperatures and soot contamination.

*A more complete description of the Diesel Engine is given in "Diesel Operation" published by The Texas Company.

HEAVY DUTY OILS

To meet this latter condition, heavy duty oils have been developed by the petroleum industry with the cooperation of the engine builders. The development of these oils is covered fully in the preceeding issue of this magazine. In varying degrees, the heavy duty oils have these characteristics:

1. resistance to the oxidizing effect of high temperatures.
2. strong cleansing or detergent action.
3. high film strength to reduce wear.
4. ability to protect bearings against corrosion.

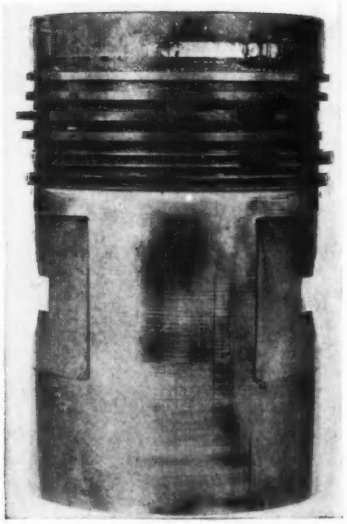


Fig. 1—Lubricating oil deposits on piston from highly supercharged Diesel showing effect of excessively high piston temperatures.

Fig. 2—Fuel deposits on piston after long idling at low jacket temperature showing effect of cold operation.

As a result, engines lubricated with heavy duty oils remain cleaner and wear less, extending the overhaul period.

The heavy duty oil is by no means a "cure-all"; good lubrication still depends upon good maintenance.

Most any engine maladjustment may react unfavorably on the lubricating oil. Exhaust back pressure, valve condition, governor adjustment, oil pump efficiency, all affect lubrication. Such items are, however, usually well covered in the instruction manuals accompanying the engine.

GRADE OF OIL

Engine manufacturers' recommendations should be followed as far as possible when determining what SAE number should be used. Sometimes this is not practical with fleets having more than one type, make or size of engine. It may be necessary to compromise. The Army has demonstrated that this can be done by standardizing on an SAE 10 oil for cold, and an SAE 30 for warm climates, using an SAE 50 grade in special installations.

The lowest temperature at which the engine must start establishes the highest SAE number which can be used. A guide in this respect is indicated as follows:

Maximum SAE Number of Oil	*Lowest Expected Temperature*
50	40° F.
40	30° F.
30	15° F.
20	5° F.
10	−10° F.
10 plus 10% Diesel fuel	−20° F.

At the same time the oil should not be too low in viscosity for safe lubrication at highest operating temperatures encountered. To maintain sufficient viscosity and prevent undue oxidation, crankcase oil temperatures should be kept under:

SAE Number of Oil	*Maximum Safe Oil Temperature*
50	265° F.
40	265° F.
30	265° F.
20	240° F.
10	220° F.
10 plus 10% Diesel fuel	200° F.

It is necessary to select the SAE number required for satisfactory starting and then maintain safe operating temperatures for that particular grade.

SELECTION OF FUEL

Fuel is sold by grades as numbers 1, 2, 3, etc. The low numbered grades in general are more volatile and burn cleaner in the high speed Diesel while the heavier grades have higher heat values and, therefore, produce better fuel economy. The choice of grade of fuel for the high speed Diesel is a compromise between the better fuel economy of the heavier fuels and the improved combustion of the lighter grades. Best results are usually secured with either a heavy No. 1 or a light No. 2 fuel. However, should the engine become contaminated with fuel soot, it may be an indication that a more volatile fuel should be used.

There are other fuel properties which affect lubrication. Cetane number is a measure of the ignitability of the fuel. The use of fuels of poor ignition quality may result in fuel varnish formation on the

piston when the engine is idling cold, making lubrication difficult. High sulfur fuels aggravate the formation of varnish.

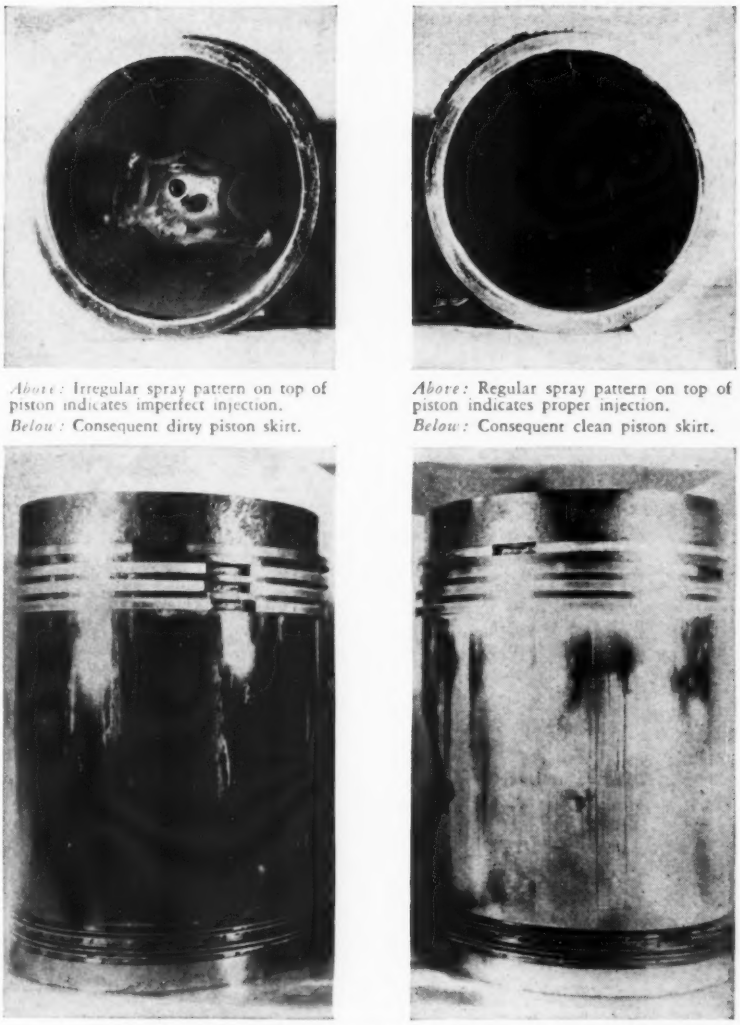
A clean, non-corrosive, non-gumming fuel, having sufficient viscosity to lubricate the pump and injector plungers, is required to insure proper functioning of the injection system. Improper injection of the fuel results in soot deposits in the engine.

FUEL INJECTION MAINTENANCE

The fuel injection system is the most important part of the Diesel engine for, upon it depends how well the fuel is burned. If the fuel is injected at the proper time and with the right spray characteristics a clean, smooth-running engine will usually result. If the fuel is not injected properly the engine will be rough, noisy, and dirty. An engine with a good injection system is not difficult to lubricate. Poor injection can cause any number of lubrication difficulties.

Improper timing of the injectors can cause lubrication trouble. If the fuel is injected too early, before the air in the cylinder has been compressed sufficiently to ignite the fuel, a large quantity of fuel will be injected before ignition occurs. Then, when the charge finally does ignite, a heavy explosion occurs within the cylinder producing excessively high pressures and temperatures. These can cause piston ring and bearing difficulties. If the fuel is injected too late sufficient time may not be available to burn all the fuel, then excessive soot deposits form in the engine. Early injection will be evidenced by a noisy, rough-running engine while late firing can be detected by a smoky exhaust.

The injectors must be properly equalized so that each delivers the same amount of fuel. If certain cylinders get more fuel than others they will carry more than their share of the load and may develop ring trouble. Those cylinders that get the least amount of fuel will be apt to miss when the engine is idling, causing fuel varnish formation on the piston and dilution of the crankcase oil. It is sometimes possible to determine that the injectors are unbalanced by either an uneven sound when the engine is under load or by a white or light blue smoke at the exhaust when the engine is idling. To determine which injectors are out of balance the speed-drop method can be used. This procedure involves cutting out one cylinder at a time and, preferably with a tachometer, noting the drop in speed that results. The speed drop will be greatest when those cylinders are cut out which are getting the most fuel. In large Diesels, exhaust temperature indicators are often installed which enable the operator to determine if all cylinders are getting the same amount of fuel. High speed Diesels are seldom equipped with thermocouples, however, pyrometers are available which can be placed against the outside of the individual cylinder exhaust outlets and any



Above: Irregular spray pattern on top of piston indicates imperfect injection.
Below: Consequent dirty piston skirt.

Above: Regular spray pattern on top of piston indicates proper injection.
Below: Consequent clean piston skirt.

Fig. 3—Pistons from same engine service run, showing effect of good and poor fuel injection on piston cleanliness.

Unetched Etched

Fig. 4—Photomicrographs (100X) of cross-section of scored linen. Metal often breaks away at flakes of graphite (black lines).

extreme variations in temperature noted. Any rust or paint should be removed from the spot where the pyrometer is applied so that a good contact is assured. Also, the pyrometer should be placed at exactly the same spot on each exhaust outlet. Firing pressure indicators can be applied to some high speed Diesels which will detect a cylinder that is not firing properly. If the offending cylinder can be detected by one of the several methods suggested then it may only be necessary to remove the offending injector and have it checked on the test stand. It is desirable, of course, to test all injectors periodically, carefully following the engine manufacturer's instructions.

Opening pressure, spray pattern and dribbling tendency should be checked when testing the injectors. Improper injection can cause washing away of the lubricant resulting in ring or cylinder wear. Poor atomization can cause ring sticking and soot contamination of the lubricating oil.

Engine manufacturers use different methods of insuring against too much fuel being injected. These mechanisms should not be tampered with. Allowing more fuel to be injected will produce more power but at the expense of ring and bearing difficulties and usually cause an objectionable exhaust condition.

JACKET TEMPERATURE

The cylinder head must be maintained at a sufficiently high temperature to burn the fuel but at the same time overheating should be avoided. Failure to keep the Diesel hot is the most frequent cause of lubrication difficulties. Most manufacturers desire their engine to be run at around 180° F. jacket temperature. At lower temperatures, soot deposits form due to incomplete combustion of the fuel. Such deposits cause ring sticking and other difficulties such as, reduction of running clearances, clogging of oil rings, filters, etc. It has been demonstrated that ring sticking is especially severe when running the engine at 100° F. and also at 275° F. water jacket temperature; this latter temperature being obtained by using ethylene glycol in the cooling system. The most satisfactory water jacket temperature, therefore, lies somewhere between these two figures and probably above 180° F. This is, however, about the maximum temperature at which water can be carried except under pressure. The water jacket temperature should not be allowed to approach the boiling point of water since the formation of steam pockets not only retards heat transfer from the engine but also may cause cylinder head cracking and other difficulties due to stress set up by uneven cooling. Overheating of the engine can also cause breakdown of the lubricating oil.

In very cold weather Diesels with radiators are usually equipped with shutters and other devices for keeping the engine up to temperature. In Canada, for instance, during the winter months, Diesels are sometimes operated with the fan belt removed and the intake air warmed by passage across the exhaust manifold. It has been noted that operators watch the cooling liquid temperature indicator very closely during the Winter season but are prone to neglect this important item during the milder Fall and Spring months. The radiator shutters on some Diesels require attention until the atmospheric temperature reaches 40° F.

Thermostats should be checked occasionally making sure that the thermostat outlet pipe remains cool until jacket temperature reaches normal.

Low cooling water temperature promotes condensation while the engine is running. Steam, one of the major products of combustion, may blow by the piston rings and condense in the engine if crankcase ventilation is poor and the crankcase temperature is below 130° F. The water vapors are most apt to condense on the top deck underneath the valve cover plate. Sludge at this point will usually be found to consist of a water-oil emulsion which can be detected by heating. When the temperature

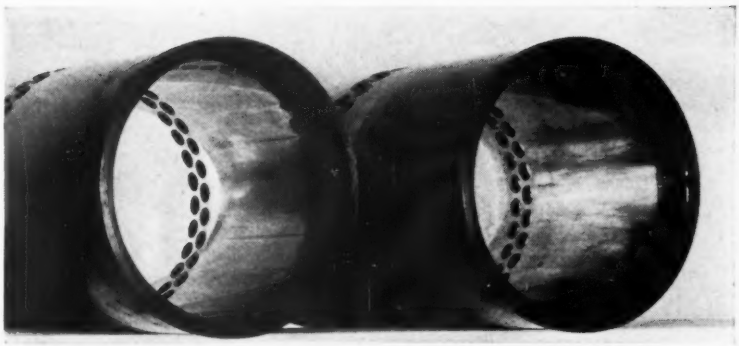
Fig. 5—Excessive deposits on top land of piston resulting from high oil consumption.

of the sludge reaches 212° F. any water present will sputter and boil off, to decrease amount of sludge.

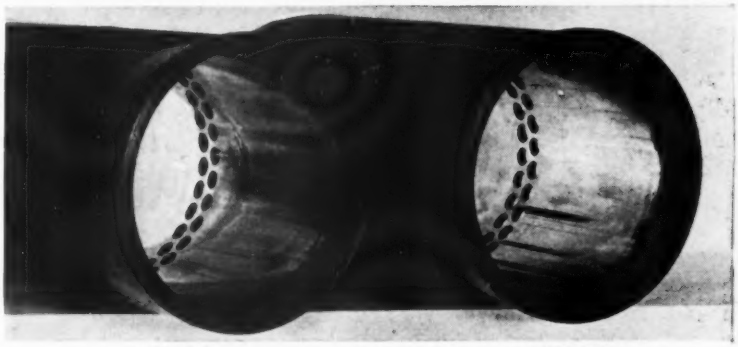
OIL TEMPERATURE

There are several points which must be taken into consideration to arrive at the correct crankcase oil temperature.

It is quite generally recognized that a more viscous oil is necessary to lubricate and seal the piston rings than is required for bearing lubrication. In large Diesels equipped with separate lubrication systems a lighter oil is supplied the bearings than is fed to the cylinders. Although only one oil is used in the high speed Diesels, the same thing is accomplished by elevating the crankcase oil temperature. Raising the oil temperatures reduces its viscosity and frictional resistance measurably improving fuel economy.



TRACE LIGHT



MEDIUM HEAVY

Fig. 6—Scored liners resulting from heavy deposit on top land of piston.

Filtration is greatly improved at higher oil temperatures. Not only does the less viscous oil flow through the filter at a faster rate but also solid particles are more readily removed.

High oil temperature prevents condensation of water in the crankcase and tends to drive off any fuel dilution.

On the other hand, oil temperatures above 250° F. may cause breakdown of the lubricating oil forming sludge and other oxidation products which dissolve lead from certain bearing metals. Formerly, when straight mineral oils were used, these were very serious considerations and oil temperatures were generally reduced to prevent excessive oxidation of the oil. With the advent of the oxidation resistant heavy duty oils, sludge formation and bearing corrosion are seldom encountered.

The greater tensile strength and fatigue resistance of bearing metals at lower temperatures is also tending to keep oil temperatures down.

Taking all these factors into consideration, an oil temperature at 180° F. appears to be a satisfactory compromise. This means that the oil and water temperatures should run about the same, which is fortunate since, in an engine the two liquids tend to reach the same temperature level; therefore, if the water temperature is properly controlled, the oil temperature will be automatically taken care of provided, of course, the oil coolers are functioning properly.

Variations of 20 or 30° F. from the recommended 180° F. are of no serious consequence except that oil consumption is affected. In a given engine, oil consumption is dependent upon oil viscosity which, in turn, decreases with an increase in oil temperature. An oil temperature rise of 20° F., on the average, reduces the viscosity to that of the next lighter SAE grade and increases oil consumption about 10%.

The four important items mentioned in the beginning of this article as contributing the most to the performance of the engine and its lubrication have now been discussed. These were: quality of fuel and lubricating oil, injection maintenance, and engine temperature. To these must be added several other maintenance items of importance from a lubrication standpoint.

BEARINGS

The Diesel engine operator should learn the characteristics of the bearing material used in the main and connecting rod bearings, as maintenance and operating practices vary with the different type metals. The manufacturer of the engine selects the

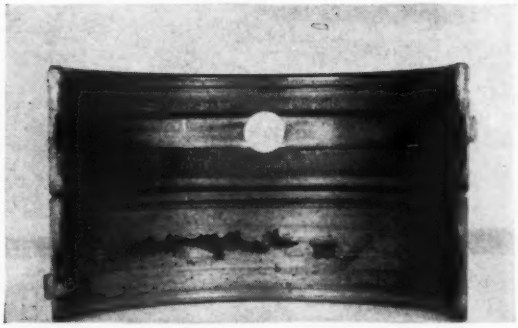
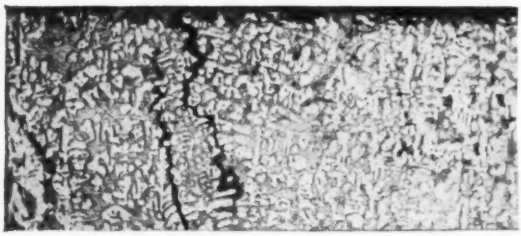


Fig. A.—Fatigue failure of copper-lead bearing.
Below: Photomicrograph (100X) of cross-section of same bearing. Presence of lead (gray area) at surface indicates no corrosion.



Soft metals, even though their good conformability tends to distribute the load evenly, are not strong enough to carry the high speed Diesel pressures. Hard metals normally have sufficient load-carrying ability but fail if pressures are concentrated on a small portion of bearing due to unyielding character of metal.

TYPICAL BEARING COMPOSITIONS, %

Copper-Lead	70 Cu	30 Pb	
Aluminum	96 Al	4 Cu	
Bronze	86 Cu	7 Pb	7 Sn
Silver	99 Ag		
Cadmium-Silver	98 Cd	2 Ag	
Hardened Lead	97 Pb	2 Sn	1 Ca
Lead-Silver Babbitt	78 Pb	15 Sb	5 Ag
Tin Base Babbitt	89 Sn	7 Sb	4 Sn
Lead Base Babbitt	85 Pb	10 Sb	5 Sn
Lead-Tin Coatings	96 Pb	4 Sn	
Lead-Indium Coatings	96 Pb	4 In	

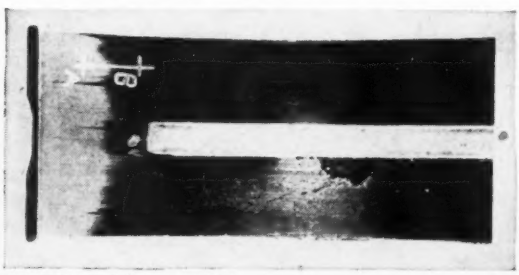
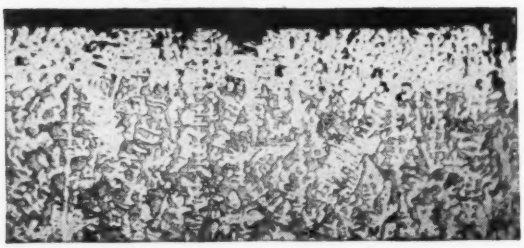


Fig. E—Corroded copper-lead bearing.
Below: Photomicrograph (100X) of cross-section of same bearing. Absence of lead (gray area) at surface indicates corrosion.



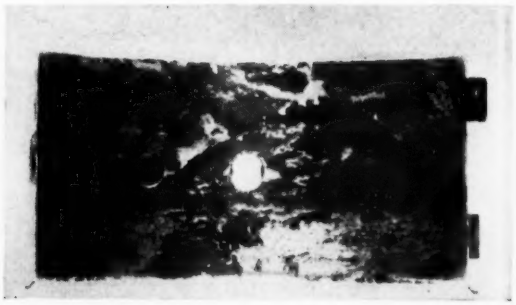


Fig. B—Carbon deposits on bearing from sludge due to anti-freeze leakage and fuel soot coagulation.

CAUSES OF FAILURE

Bearing Structure:

Improper type bearing material.
Bearing metal improperly manufactured.
Incorrect design of replacement bearings.
Inferior bonding.
Weak of thin bearing back.

Bearing Installation:

Unclean bearing surfaces.
Dirt or foreign particles between backs of precision type bearings and main or connecting rod bores.
Improper fit of precision type bearings in bores and caps.
Improper oil clearance.
Misalignment of caps.
Filing of caps.
Improper tension on bolts.
Misalignment of crankshaft, cylinder, connecting rod or main bearing saddle bores.
Out-of-round, scored or worn crankshaft journals and crankpins.
Use of shim stock with precision inserts.
Oil holes in bearings not lining up with holes in bores.

Operating and Maintenance Conditions:

Lugging at low engine speeds.
Overspeeding engine.
Low oil pressure.
Restricted oil passages.
Infrequent and improper oil filter, air cleaner and crankcase breather maintenance.

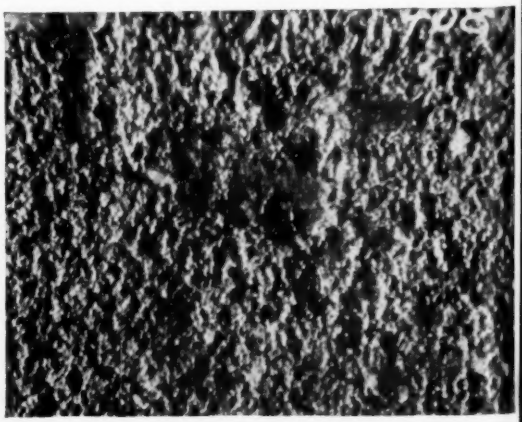


Fig. F—Close-up of corroded cadmium silver bearing.

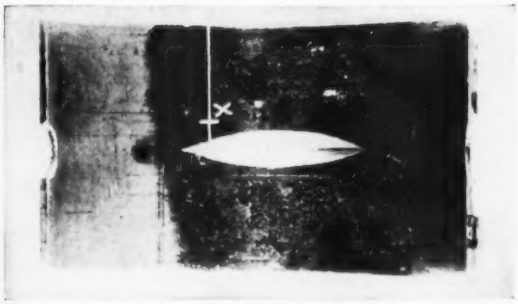


Fig. C—Effect of poor bearing fit; shaft riding on only part of bearing area.

ENGINE BEARINGS

High pressures from cold starts.
Extended oil drain periods.
Improper operating temperatures.
Improper grade of oil used.

Contamination of lubricant:
- Fuel dilution. Cooling system leakage. Condensation.
- Fuel soot. Metal from engine wear. Dirt. Rust.

Corrosion:

Bearings not corrosion resistant.

Improper type of lubricating oil.
- New oil has insufficient resistance to oxidation.
- Reclaimed oil from which corrosion-inhibiting additive has been removed.

High oil temperatures.
- Faulty cooling system.
- Insufficient crankcase ventilation.
- Low oil level.
- Too heavy viscosity oil.
- Overloading.
- Clogged oil cooler.
- Insufficient heat dissipation from crankpan.
- Insufficient oil pump capacity.

Extended oil drain periods.

Oil contamination with acidic fuel combustion products (low temperature corrosion).

Addition of unsuitable materials to the oil by the user.

Use of oil filters which remove corrosion-inhibiting oil additives from some oils.

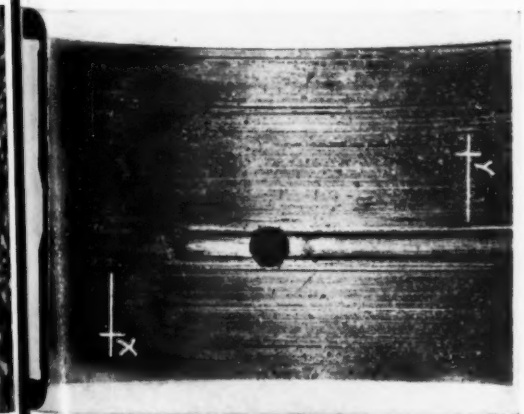


Fig. G—Tell-tale streaks left by dirt which caused bearing failure.

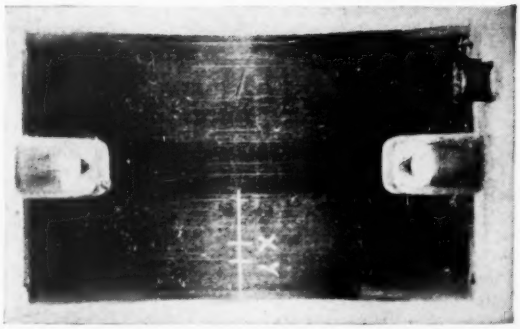
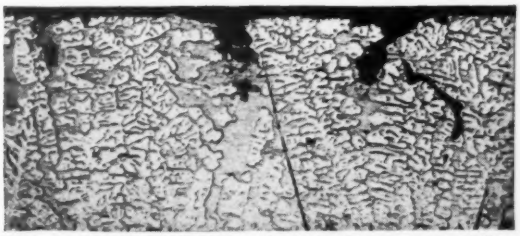


Fig. D—Copper-lead bearing, pitted due to lead segregation.
Below: Photomicrograph (100X) of same bearing showing lead has fatigued or melted out where lead was improperly segregated.



When using soft bearings, avoid overloading or overspeeding, keep bearing clearances close and oil temperatures down. When using hard bearings, air cleaners and oil filters should receive frequent attention and other steps taken to make certain oil is kept clean; fit bearings carefully with ample clearance.

PROPERTIES OF METALS

	Symbol	*Brinell Hardness*	*Melting Point °F.*	*Thermal Conductivity*
Hardened Steel Shaft	Fe	600	2600	.2
Steel Shaft	Fe	250	2600	.2
Copper	Cu	75	1980	.9
Antimony	Sb	75	1170	.1
Silver	Ag	38	1760	1.0
Aluminum	Al	22	1220	.5
Cadmium	Cd	22	610	.2
Tin	Sn	5	450	.2
Lead	Pb	4	620	.1
Indium	In	3	320	.1

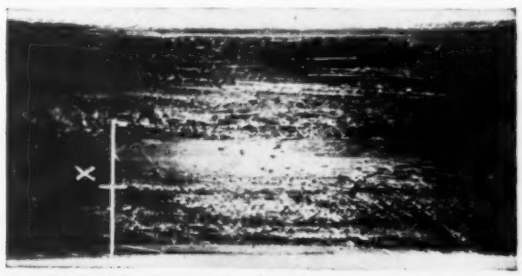


Fig. H—Pitted bearing resulting from foreign particles pounding or "brinelling" surface in passing through bearing.
Below: Photomicrograph (100X) showing particles and indentation.

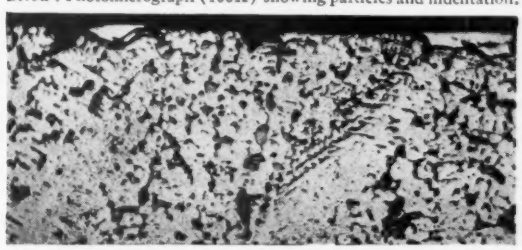


Fig. 7—Air ports clogged with products of incomplete combustion due to operating engine cold.

bearing material most suited to the particular application; it is quite essential, therefore, when replacing bearings, to use the type recommended.

For least wear the bearing material should be soft so that any abrasive particles reaching the bearing will become completely embedded and not project and wear the shaft; also the softer metals better conform to any shaft misalignment or machining irregularity. Tin, by itself, is too soft but when hardened by the addition of antimony and copper (babbitt) meets these requirements. Then, too, tin has a fairly low melting point so that, when localized overheating occurs, the tin melts relieving the high spot before the oil film is burnt off. Tin babbitt is non-corrosive and has ideal anti-friction qualities but, as engine speeds and pressures increased the babbitt in some installations quickly cracked due to fatigue resulting from the more frequent applications of higher peak loads. It was found that adding a small amount of lead or bismuth, lowered the bearing strength, while adding more copper or antimony embrittled the bearing, lowering its resistance to shock. It was necessary, therefore, to investigate base metals other than tin.

Lead, always more plentiful than tin, has been subjected to intensive study by bearing manufacturers. In the pure state, it is too soft and is subject to corrosion by some of the acids formed by oxidation of the lubricating oil in service. Lead-base babbitt is made by adding antimony and tin to increase hardness and corrosion resistance. Silver may also be added to increase the fatigue resistance. The lead base metals have nearly the same hardness and load carrying ability as the tin base babbitts. Ordinarily, no difficulty due to corrosion is encountered.

Lead, hardened by the addition of a small amount of calcium (hardened lead), is as hard as tin-base babbitt and more resistant to fatigue especially at higher temperatures. It is more susceptible to corrosion but this is partially overcome by the addition of a small amount of tin. Too much tin in this case, however, seems to weaken the structure. As the thermal conductivity of lead is rather low, lead bearings are often furnished with bronze backs.

By reducing the thickness of the soft-metal, there is less deflection under load and the fatigue resistance is increased so that lead and tin-base bearings can be used in Diesels when loads and speeds are not too high. When the soft bearings are used, overloading and overspeeding cannot be tolerated and firing pressures should be kept down by properly adjusting injection timing and using a high cetane fuel.

In the high speed Diesel, greater power and a reduction in exhaust smoke can be obtained by advancing the injection timing, resulting however in higher firing pressures and greater maximum loads on the bearings. In a typical case, maximum connecting rod bearing pressures varied with injection timing as follows:

Injection Timing Degrees Before TDC	*Maximum Bearing Pressure lbs./sq. in.*
0	1725
5	2025
10	2430
15	3000

An increase in the cetane number of the fuel will reduce the bearing pressures, for example:

Cetane Number	*Maximum Bearing Pressure*
30	3090
40	2700
50	2430
60	2370

Since the maximum allowable bearing pressures for tin and lead-base bearings are around 1400 lbs./sq. in. it is obvious that a different type of bearing had to be found for the high speed Diesel. The most promising materials having higher load-carrying ability are: silver, copper, aluminum and cadmium.

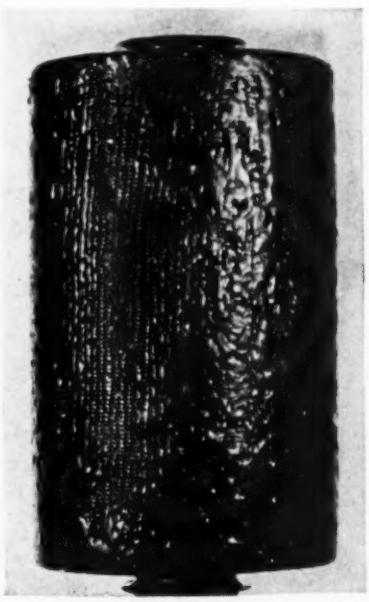


Fig. 8—Sludge deposits resulting from excessive fuel soot contamination of lubricating oil.

Cadmium plus a little silver or nickel produces a bearing which is a good compromise between the high fatigue resistance of copper and silver and the good anti-friction properties of tin and lead. Comparative tensile strengths at various temperatures in lbs./sq. in. are:

Temperature, °F.	*Tin Base Babbitt*	*Cadmium Silver*
100	9,700	16,700
200	7,000	12,500
300	4,300	8,200

Cadmium, however, is subject to oil corrosion. By keeping oil and bearing temperatures low, the possibility of corrosion is reduced and the bearing strength and life increased.

Aluminum, alloyed with copper, is harder and somewhat stronger than babbitt but does not have the fatigue resistance of either silver or copper. That it has good bearing properties for certain applications is evidenced by the fact that aluminum pistons are not fitted with wrist-pin bushings. The anti-friction qualities of aluminum are not well established but freedom from corrosion, good heat transfer and light weight encourage its use.

Silver has the best fatigue resistance and heat transfer of any of the metals considered. It is much softer than copper but harder than babbitt. Its tendency to score under certain conditions and the high cost, however, have limited its use.

Bronze bearings, of copper alloyed with tin and lead and zinc, have been used where temperatures are high and shock loads severe, as in wrist-pin bushings in cast iron pistons. Rather poor conformability, embeddibility and anti-friction qualities have discouraged its use in connecting rod or main bearings, except for the loaded half of two-cycle engine bearings, in conjunction with a white metal unloaded half.

To take advantage of the high load-carrying ability of copper and the good anti-friction characteristics of lead, the copper-lead bearing was developed. In this type bearing nearly pure lead globules are dispersed throughout a copper matrix. The lead, of course, is subject to corrosion and only corrosion-resistant oils should be used. This bearing, while proving very satisfactory in many high speed Diesels, still does not possess the conformability and embeddibility of babbitt; therefore, shafts must be hardened, larger bearings clearances employed, oil carefully filtered and care exercised when fitting replacement bearings.

Tri-metal bearings are also being used to obtain the desired qualities of both the hard and soft metals. A lining of metal having high resistance to fatigue and fair friction qualities, such as silver, copper-lead or bronze, is first bonded to the bearing backing. Over this basic lining a thin coating of soft metal, having good anti-friction characteristics, is applied. These surface coatings may consist of lead or tin-base babbitt, hardened lead or even very soft lead with a little indium or tin added to inhibit corrosion.

Further interesting bearing developments can be expected and it is a subject which Diesel engineers should follow closely.

AIR CLEANERS

Air cleaners should be kept in efficient working order to prevent wear. Not only must the oil be changed in oil bath type air cleaners frequently, sometimes after only a few hours operation, but occasionally the entire cleaner should be disassembled and cleaned. The use of the right viscosity oil is necessary to secure best performance. Instructions on the air cleaner should of course be followed in selecting the proper grade. Too heavy an oil will not clean the air while too light an oil may carry over dirt into the engine. Since the viscosity of oil drainings from the engine is usually an unknown quantity, due either to thinning from dilution or thickening from oxidation, used oil even though clean should not be applied to the air cleaner except under emergency conditions. If, upon removing the air cleaners, oil is found in the intake manifold, make certain that the oil in the cleaner, is not too light and check whether the engine has been run at excess speeds. If dirt is present in the intake manifold then air cleaner maintenance should be checked and the manifold should be inspected for air leaks.

OIL FILTERS

Oil filters must not only be changed and cleaned when necessary but consideration also should be given to the type and size of filter installed. A filter containing a very efficient purifying medium is of little value if it is too small, or if oil temperature

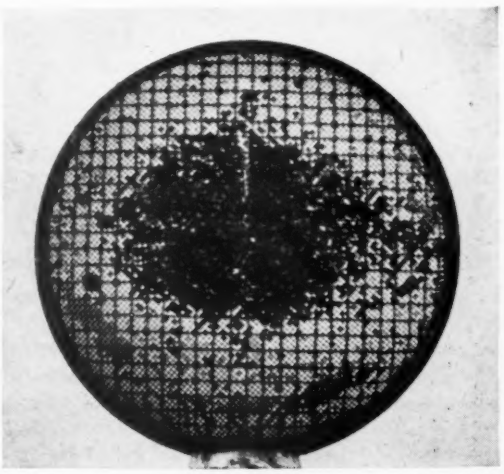


Fig. 9—Pump screen deposits resulting from cleansing action of detergent oil when first placed in dirty engine.

Fig. 10—EXHAUST VALVE DEPOSITS

High temperature causes carbonization on valve stem. Low temperature operation causes fuel varnish on valve head. Metallic deposits, aluminum, from engine wear.

and pressure are so low that only a small amount of oil passes through it. Illustrating the difference in the amount of purification obtained from different types of filters are these results of bench tests in which the same dirty oil was fed through different high speed Diesel filters when tested separately in the same pump installation.

Filter Designation	*Carbonaceous Material, % after Filtration*	*Detergent Content, % after Filtration*
A	.33	.26
B	.16	.33
C	.07	.30
D	.05	.22

Since the carbonaceous content of the oil before filtration was 0.8%, all the filters removed a considerable portion. However, some of the filters cleaned up the oil much better than others. There is no significant variation in the detergent content indicating that for this particular heavy duty oil all types of filters, whether they be clay, waste, or paper, remove about the same amount of detergent additive—presumably the spent portion.

Strainer type filters in turn must be properly maintained. Forcing a cleaning solution through under pressure is the only real way to clean fine oil strainers.

ENGINE OVERHAUL

In addition to periodic inspection and regular servicing, Diesels should be overhauled at definitely established intervals. Such preventive maintenance is the most effective way of forestalling failures and reducing operating costs. If the engines are taken apart, cleaned up, adjusted, and a few worn parts replaced at set periods, repair costs will be at a minimum. On the other hand, if an operator waits until signs of engine failure are evident, when it is finally decided to overhaul the engine, it is very apt to be an expensive job. Why wait until rings are stuck or worn so that the engine is pumping oil and has lost power before cleaning pistons? Worn or stuck rings can cause scoring of pistons and cylinders before the power and oil consumption are affected. Why wait until there is a knock in the engine, or the oil pressure drops, or flakes of bearing metal are found in the oil filter, before checking the bearings? By catching a bearing in the process of failure a whole set of bearings may be saved by preventing bearing particles from going through the engine, scoring the rest of the bearings. Why wait until exhaust smoke is observed before testing the injectors? Soot deposits form, causing numerous difficulties often long before the engine starts to smoke. If there is any doubt as to the value of preventive maintenance a visit to any shop where it is practiced will confirm that it pays.

Many bus or truck operators overhaul at approximately 100,000 miles depending on local conditions. Semi-annual overhauls are desirable in most other types of installations where the engine is in continuous operation.

Any sort of maintenance program requires the keeping of records of mileage, fuel and oil, repairs, and other services performed on the engines. Such records should be sufficiently simplified so that they can be kept up-to-date and instantly available for reference.

High speed Diesels do not require elaborate shop instruments to keep them in tune. The absence of carburetors and ignition systems greatly simplify the service problem. However, a test stand for testing injectors is an absolute necessity.

The Diesel is not a complicated machine and few adjustments are necessary when overhauling an engine, in fact, the less tampering the better. The primary purpose of the overhaul is to remove dirt and carbon and to replace worn or broken parts, therefore, thorough cleaning, careful wear measurements, and close inspection of all parts should be stressed. A few of the more commonly neglected points which should be checked are:

Clean all parts thoroughly as removed, placing in clean place protected from dust and dirt.

Machined surfaces should be oiled to prevent rusting while awaiting replacement.

Fig. 11—Scored piston, bearing and wrist pin resulting from a few minutes' operation after starting cold on diluted oil.

Plug fuel lines to prevent entrance of dirt.

After handling polished injector parts; they should be wiped carefully as finger marks cause etching.

Oil handling equipment collects dust. Measuring cans, etc., should be rinsed well before using.

Clean all oil lines carefully.

Clean bearing backs and saddle bores so that there will be a good fit between the two.

Polish any rough spots on crankshaft, cylinder, or piston.

Use torque wrench for tightening bearing, cylinder head, injector and other hold-down bolts where an even tension is necessary to prevent distortion and binding.

Handle bolts carefully so as not to burr the threads which would prevent proper tightening with the torque wrench.

Remove scale from cylinder water jacket.

The fact that these points are so obviously essential to the proper overhauling of an engine is possibly the reason why they are often overlooked.

USED OIL ANALYSIS

Every Diesel engineer is familiar with the engine indicator which measures pressure within the combustion chamber. From the cards taken by this instrument a rather complete knowledge of what is happening inside of an engine is obtained. Few are aware of another indicator which also tells what is going on inside an engine. This is the laboratory analysis of the oil from the crankcase. Physical, chemical and mechanical tests have been developed which measure the changes that have taken place in the oil due to engine operating conditions. From a study of the changes that have occurred in the oil it is possible to determine what the conditions of operation are inside the engine. Similar tests are applied to deposits which reveal the engine condition responsible for their formation.

The lubrication engineer can, by studying the used oil analysis, tell pretty well if correct jacket and oil temperatures are being maintained; if injectors are adjusted properly; if wear is taking place; if dirt is getting into engine; if there is a water or fuel leak; if bearing corrosion is possible; if oil filtration is effective and if oil is being changed when necessary. When intelligently used it is an invaluable aid to proper operation and maintenance.

OPERATION

Turning now to the question of operation; the man behind the steering wheel or the engine controls can greatly extend the engine life, by proper handling.

One of the most important variables, which affect lubrication, in the hands or, more properly, under the foot of the operator, is the throttle by which the amount of fuel entering the engine is controlled. After the engine is started the throttle should be held at a fast idling position only long enough for the oil to become well circulated, as indicated by the oil pressure gauge. When the engine is cold the temperatures in the cylinder are not high enough to completely burn the fuel and a heavy coating of fuel varnish forms on the valve stems and pistons. In fact, if an engine is allowed to idle with cold jackets, the engine will stop after a few hours of such operation and, if the varnish is allowed to set, the engine cannot be restarted. Most of this varnish can be burned off however by running the engine hot. As soon as practical after starting, a light load should be put on the engine. When the jacket temperature has reached normal, full load can be placed on the Diesel and most of the fuel varnish, formed when starting, will be removed. Once the engine is hot it can be idled without danger of varnishing unless the jacket temperature falls.

Engine load and speed greatly affect the rate of soot contamination of the lubricating oil. The greater the load, the faster the contamination, which is particularly severe if the engine is required to pull heavy loads at low speeds, otherwise known as "lugging."

Engines should not be allowed to idle at low jacket temperature just prior to shutting down, otherwise varnish may form and set permanently.

Engine bearings are designed to withstand certain load and speed conditions. The bearings normally furnished will usually stand up under full throttle operation. However, if an engine is overspeeded, the upper main and the lower connecting-

rod bearings may fail prematurely. If inferior bearing materials are being used, the engine speeds and loads may have to be reduced in order to obtain reasonable life from the poorer quality bearing material.

The effect of injecting more and more fuel up to twice that required to pull the rated load of the engine is given for one 4-cycle Diesel:

TABLE I

Fuel/Air Ratio	*Percent Rated Load*	*BMEP*	*Percent Exhaust Smoke*	*Ring Grove Temp.*
.03	67	51	7	336
.04	100	76	7	372
.05	112	85	16	396
.06	114	87	69	402
.07	113	86	92	397
.08	111	84	97	388

At overloads lubrication is more difficult due to higher ring temperatures and greater soot formation. Little power was gained when more than 25% additional fuel (.05 F/A ratio) was injected and exhaust smoke became excessive.

Cold Starting

Below −10° F. auxiliary means for keeping the engine warm should be provided. If such heat is not available, the crankcase oil may be diluted, before shutting down, with just sufficient Diesel fuel to permit restarting. 10% is suggested for temperatures down to −20° F. This practice is not recommended except as an emergency measure, as excessive dilution may accumulate after repeated applications. When operating at such low temperatures the oil should be changed more often otherwise roughened bearings and scored pistons may result from operating on diluted oil. Piston scoring has also occurred when starting on too heavy an oil. Specifically, an SAE 30 oil caused scoring at 0° F. which did not occur when an SAE 10 oil was used.

The contraction of engine parts in very cold weather may cause mechanical difficulty. Wrist pin clearance, for example, is sufficiently reduced at low temperatures, so that scuffing of the wrist pin and scoring of the cylinder liner may occur when the engine is started. Main bearing clearances are considerably reduced in those engines having through bolts extending from the main bearing caps through the cylinder heads. The contraction of these long bolts can tighten the main bearings so that scuffing occurs when starting.

There are, of course, many other problems which must be solved in order to start engines in very cold weather. Those mentioned are the principal ones of concern from a lubrication standpoint.

SUPERCHARGING

Supercharging gives rise to several lubrication problems. The higher pressures inside the cylinder increase both the bearing and the piston ring pressures. In the lubrication of the high speed Diesel, however, the effect on ring sticking is the primary concern. The principal engine conditions which control ring sticking are: 1: — ring temperature which governs the amount of lubricating oil oxidation-products formed; and, 2: — completeness of combustion which determines the amount of fuel soot deposits in the ring belt.

In a specific case comparing conditions with no supercharging with the same engine having a 10 inch boost pressure it was found, that 10% extra power could be obtained by supercharging without raising the piston ring temperature with a reduction in exhaust smoke. As more fuel was injected, until the same amount of exhaust smoke was emitted as when running unsupercharged, 37% more power was obtained but piston ring temperatures rose 63°.

Analyzing these results; if a standard 100 horsepower Diesel was supercharged and run at 110 horsepower output, ring temperatures would not be increased and the amount of soot formed would be less and therefore the ring sticking tendency would be reduced. If, however, 137 horsepower was developed, soot formation would be the same as in the unsupercharged engine but piston ring temperatures would be higher and ring sticking more apt to occur. Ring sticking tests run on this engine confirmed this analysis.

It is concluded, therefore, that supercharging reduces ring sticking at part loads but accelerates it at loads approaching full power output due to higher piston ring temperatures. The engine designer, therefore, when supercharging should increase the amount of piston cooling. If this cannot be done piston clearances must be increased to provide for the hotter running piston and other methods of reducing ring sticking adopted.

* * *

When the high speed Diesel was first proposed for automotive service, many were hesitant to adopt this new form of power for fear that higher maintenance costs would offset the admittedly better fuel economy. Experience has proved that this is not the case, and that the high speed Diesel when properly cared for and operated, has a wide field of application. This article is a record of those operating practices which experience has demonstrated will insure satisfactory lubrication and economical performance.

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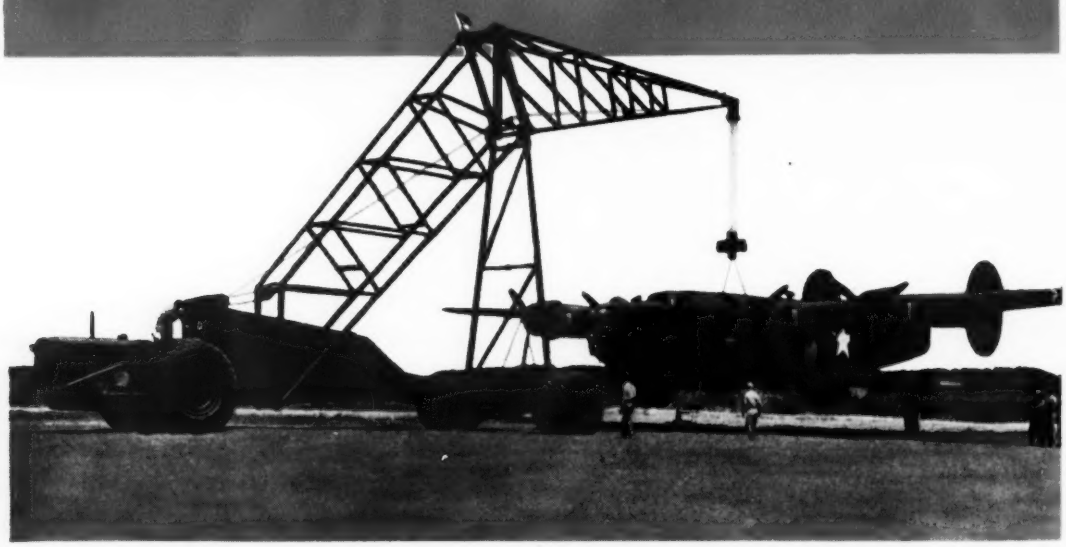

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